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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	
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COLLIER et al.	)	Examiner: Nguyen, David
	)	
Serial No.: 09/618,296	)	Group Art Unit: 2682
	)	
Filed: July 18, 2000	)	
	)	
For: **Variable Oscillator**	)	

DECLARATION UNDER 37 C.F.R. §1.131

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

We, James Digby Yarlet Collier and Ian Michael Sabberton, declare as follows:

1. We are the same James Digby Yarlet Collier and Ian Michael Sabberton named as co-inventors in the above-identified U.S. patent application.

2. Attached hereto as Exhibit A is a copy of a draft patent application, the original of which was prepared in Great Britain prior to April 2, 1999, although the actual date has been deleted on the attached copy. The draft patent application presented in Exhibit A establishes conception of the invention in Great Britain prior to April 2, 1999, after which the above-referenced application was prepared with due diligence and diligently filed in the United Kingdom on July 19, 1999 as application No. 9916907.0. The accompanying Exhibit A thus establishes conception of the invention set forth in the claims in the above-referenced application prior to April 2, 1999, coupled with due diligence from prior to that date to the July 19, 1999 effective filing date of the present application under 35 U.S.C. §119.

3. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so

made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1 April 2003
Date

James Collier
James Digby Yarlet Collier

1. April 2003
Date

Ian Michael Sabberton

Attachment: Exhibit A

1417-180-Rule 131 declaration.131

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VARIABLE OSCILLATOR

This invention relates to variable oscillators, in particular oscillators whose frequency of oscillation is variable in response to a frequency setting signal and which can be trimmed by means of a separate trimming signal.

Figure 1 shows one form of variable oscillator. The circuit of figure 1 includes a resonant portion 1, which produces an oscillating signal at 2, and an output stage 3, which enhances the signal at 2 by sustaining the resonance of the resonant portion and amplifying it to yield an oscillator output signal at 4. The resonant portion comprises a capacitance 5 and an inductance 6 connected in series. The capacitance is a variable capacitance ("varicap") diode 7, whose capacitance varies in dependence on the voltage applied at a control input 8. Thus the frequency of the oscillator can be varied by means of that voltage, and the oscillator is a voltage-controlled oscillator.

In many applications of oscillators such as the one shown in figure 1 there is a need to arrange the oscillator accurately so that a pre-defined range of frequencies can then be ~~scanned~~ tuned over exactly using the varicap diode 7. For example, in many communications applications the oscillator may be required to operate at one of a number of pre-defined frequencies that correspond to the frequencies of available communication channels. In order for the communications terminal that uses the oscillator to establish communication with another terminal the frequencies used by the two terminals must match each other precisely. In production there is often significant variation between the values of the circuit components between individual oscillators. This is especially significant when the oscillator is built on-chip. (Typical variation in the values of on-chip components are: ±30% for resistors, ±10% for capacitors and ±7% for inductors; the values also being strongly dependant on temperature). Therefore, it is common for the oscillator to be trimmed after production so that the pre-determined channel

frequencies can then each be selected by applying a corresponding channel-setting voltage at the control input 8.

One way to perform the trimming operation is by using the varicap diode 7 itself. A trimming offset voltage can be applied to the control input 8 to ensure that when the channel-setting voltages are also applied to the control input 8 the pre-determined channel frequencies are generated accurately. However, this approach requires the varicap diode 7 to have sufficient throw (range) to be capable of adjusting the resonant frequency not just over the frequency envelope of the available channels but also over an additional range to cope with the need for trimming the circuit. The required total throw is typically around 30%. The effect of this is that, compared to one of smaller throw, the varicap diode is more sensitive to the voltage at the control input 8. As a result, in normal operation it is more difficult to control the varicap diode accurately. Furthermore, the wide pull range implies that much of the oscillation energy of the circuit passes via the varicap diode 7, which typically has much higher losses (i.e. lower Q) than a fixed value capacitor. High loss causes poor phase noise, which substantially degrades the performance of the receiver: a typical requirement is delay matching to better than 0.5°, and at an operating frequency of 2.45 GHz this corresponds to only 0.65 ps. Another problem is that if the varicap diode has a large throw then the variation in voltage at the control input 8 as a result of the oscillation can itself alter the capacitance of the varicap and therefore modulate the frequency of the circuit. In addition, where the oscillator is used with a phase-locked loop (PLL) the wide range of effective capacitance of the varicap 7 means that the loop gain of the PLL is subject to variation. This results in poor settling, which is not compatible with the rapid jumps needed for frequency hopping systems. Although this can be addressed by introducing an adjustment for the loop time constant, this is an expensive operation during manufacture.

Another approach is to use the circuit of figure 2. In figure 2 like components are numbered as for figure 1. In the circuit of figure 2 an additional off-chip mechanical trimmer 9 is provided in the capacitative portion 5 of the oscillator.

This allows a varicap diode of smaller throw to be used. However, the off-chip component is bulky, relatively expensive and requires an inconvenient step of mechanical adjustment during production. As an alternative to a mechanical trimmer the capacitance 9 could be provided by an on-chip capacitor that can be adjuster during production be laser trimming. However, this approach is inconvenient because it can only be done before the integrated circuit (IC) is packaged, and expensive because the laser trimming step has a low yield and demands a modified IC process.

There is a need for a variable frequency oscillator that can be trimmed more easily and economically, without significant deterioration in performance.

According to the present invention there is provided a variable frequency oscillator comprising: an oscillatory circuit for generating a periodic output dependant on the capacitance between a first node and a second node of the circuit, and having a capacitative element connected between the first node and the second node; the capacitative element comprising: a variable capacitance unit, the capacitance of which is variable for varying the frequency of the output; and a plurality of trimming capacitances each being selectively connectable between the first node and the second node to trim the frequency of the output.

Preferably the variable capacitance unit connected between the first node and an intermediate node, and the trimming capacitances are each selectively connectable in series with the variable capacitance unit between the intermediate node and the second node. A switch (preferably an electrically sensitive switch such as a transistor) is suitably connected in series with each trimming capacitance between the intermediate node and the second node for selectively connecting the respective trimming capacitance between the intermediate node and the second node in response to a respective switching signal.

The oscillator may comprise control apparatus for causing a set of the trimming capacitances to be connected between the first node and the second node. The

oscillator may also comprise a memory coupled to the control apparatus for storing information defining one or more sets of the trimming capacitances. The control apparatus and/or the memory may also perform other functions in any device of which the oscillator forms part. Each of the said one or more sets may correspond to a respective operating frequency of the oscillator. The control apparatus may be capable of retrieving the information defining one of the sets in response to information defining an operating frequency being supplied to the control apparatus. The control apparatus may be capable of retrieving from the memory information defining one of the sets and then causing that set of the trimming capacitances to be connected between the first node and the second node.

At least one of the trimming capacitances may have a different capacitance value from another of the trimming capacitances. Preferably all of their values are different.

The capacitance of the variable capacitance unit may be variable by means of the voltage applied to an input of the variable capacitance. There may be feedback apparatus such as a phase-locked loop connected between the output and the variable capacitance input for stabilising the oscillator.

The oscillator, or the oscillatory circuit, is preferably formed on a single integrated circuit.

The present invention also provides a method for operating a variable frequency oscillator as described above, the method comprising: retrieving from the memory information defining a set of the trimming capacitances; connecting that set of the trimming capacitances between the first node and the second node; comparing the voltage at the variable capacitance input with a first preset voltage range; and if that voltage is outside the first preset voltage range determining, based on the voltage at the variable capacitance input, an adjusted set of the trimming capacitances and storing in the memory information defining that adjusted set of

the trimming capacitances. The said step of determining may be performed only if the voltage at the variable capacitance input is inside a second preset voltage range. In the step of storing, the information defining the adjusted set of the trimming capacitances may be stored so as to replace in the memory the said information defining a set of the trimming capacitances.

The present invention will now be described by way of example, with reference to the accompanying drawings, in which:

figure 3 shows the circuit of a variable frequency oscillator; and

figure 4 shows a control arrangement for the circuit of figure 3.

In figures 3 and 4 like components are numbered as for figure 1.

Figure 3 shows a variable oscillator circuit for a radio terminal, which can be implemented on a single integrated circuit. The variable oscillator circuit shown in figure 3 comprises a resonant section 1 and an output stage 3. The resonant section includes a capacitative section indicated generally at 5 and an inductive section 6. In the circuit of figure 3 the capacitative section 5 includes an array of switchable trimming capacitances 10, 11, 12 etc. which can be selectively switched into the resonant circuit by respective transistors 13, 14, 15 etc. to allow the circuit to be trimmed digitally.

In more detail, the resonant section of figure 3 includes an inductance 16 connected between node 17 and the output 2 of the resonant section. The capacitors 10-12 are connected in parallel between node 17 and node 18. In series with each capacitor 10-12 is a respective switching transistor 13-15. Each switching transistor is connected so that when a suitable voltage is applied to its gate from the corresponding switching input line 19-21 current can flow between its source and drain so that the capacitor with which it is connected in series is coupled between nodes 17 and 18. A varicap diode 7 is connected between node 18 and node 22. Node 22 receives a voltage input from 8 to select the operating frequency of the oscillator in use. Node 22 is decoupled from ground at radio frequency by decoupling capacitor 23.

After the circuit has been manufactured on-chip it can be trimmed by switching one or more of the capacitors 10-12 etc. fully into or out of the circuit between nodes 17 and 18 and thereby altering the effective capacitance of the whole capacitative section 5 of the oscillator.

The trimming of the circuit could be performed each time the terminal is turned on, for example by comparing the output of the circuit with a standard received frequency. Alternatively, the trimming operation could be performed at the manufacture stage. Since each trimming capacitance is switched fully into or out of the circuit the trimming is a digital operation. The setting of the switching transistors 13-15 etc. can be represented as a binary number with one digit corresponding to the switching input to each switching transistor. The setting of the trimming capacitors can therefore be stored digitally by memory of the radio terminal during manufacture or use and reproduced exactly when required by recalling the appropriate setting from memory. More than one setting could be stored (either at manufacture or during use) for different applications, such as different operating frequencies or temperatures.

Figure 4 shows one preferred arrangement for controlling the oscillator 1, 3. The output of the oscillator passes to a PLL 24 comprising a phase detector 25 and a divider 26. These feed back to the input 8 of the oscillator. The switching inputs 19-21 etc. of the oscillator are driven from an oscillator control unit 27. The control unit is under the supervision of a main processor 28 of the radio terminal. The control unit 27 monitors the voltage at input 8. The control unit adjusts the switching of the trimming capacitors with the aim that the voltage at 8 is as close as possible to a preset value. By performing this operation at each operating frequency of the terminal the control unit 27 keeps the loop gain of the circuit relatively constant.

The control unit 27 could retrieve preferred settings for the switching inputs 19-21 etc. at each operating frequency from memory 29. To switch frequencies the

control unit could then apply the stored settings to the inputs 19-21 and leave the analogue PLL to settle any residual frequency error. In this arrangement there could be no need for the control unit to influence the voltage on input 8 directly, so the oscillator control could be fully digital. The combined setting of the inputs 19-21 etc. could be viewed as a multi-bit binary trimming set signal from control unit 27.

The table of trim code settings for the switching inputs 19-21 could be stored in memory (e.g. as a table of multi-bit binary numbers) by the control unit 27, during start-up or as a background task, or during manufacture of the terminal. One algorithm for assembling the table during use is as follows:

1. Apply to the switching inputs the digital code stored in the look-up table for an operating frequency.
2. Wait for the PLL to stabilise.
3. Digitise the voltage at the varicap input 8 by means of an A-D converter in the control unit 27.
4. Compare the digitised voltage with a first preset voltage window. If the voltage is inside the first preset window then keep the present digital code setting.
5. If the voltage at the varicap input is outside the first preset window then compare the digitised voltage with a second, wider preset window. If the voltage is inside the second preset window then maintain the present digital code settings for the current radio activity (e.g. for transmitting or receiving a packet or burst of data) but adjust the code stored for the present frequency so as to increment or decrement (as appropriate) the trimming capacitance that is switched in for the present operating frequency. The adjusted code will then be employed the next time the present frequency is chosen.
6. If the voltage at the varicap input is outside the second window (in which case the unit is off-tune) abort the current radio activity and enter a re-calibration mode.

This method could also be used during a built-in self-test (BIST) operation in the terminal. The above method could be cycled through for each operating

frequency. A self-test feature of this type can yield significant cost savings during production and is desirable for ensuring proper operation during use.

The array of capacitors may include any number of capacitors from two upwards. The values of the trimming capacitors could be the same or different. If the values of the trimming capacitors are different then the same number of trimming capacitors can be used to allow trimming over a wider range, saving on IC real estate. The trimming capacitors could suitably provide 128 equal steps of total capacitance. This could, for instance, be achieved by 128 capacitors of the same value, or 7 capacitors of values scaled as 2^n.

In the re-calibration mode the control unit 27 could repeatedly monitor the voltage at the varicap input and increase or decrease the effective total trimming capacitance by switching one or more trimming capacitors in or out as appropriate until the varicap input voltage is within the first or second window. If the values of the trimming capacitors are the same then a very simple trimming algorithm can be used in the control unit 27 to adjust the effective total trimming capacitance monotonically simply by switching in more or fewer capacitors. If the values of the capacitors are different then the trimming algorithm should take this into account.

Step 5 of the algorithm set out above is especially beneficial because it allows for gradual changes to counteract drifts (due, for instance, to temperature fluctuations) without the need for full re-calibration.

The trimming capacitors 10-12 are in parallel with each other but in series with the varicap 7. This arrangement helps to allow the circuit to be set to an accurate tolerance.

The value of the varicap 7 is preferably large relative to the total of the other series capacitance in the capacitative section 5 - preferably 5 to 10 times the other capacitance. This tends to allow the effective Q of the varicap in the oscillator to be higher than its actual Q - for instance by 5 to 10 times.

The radio terminal could be a radio transmitter and/or receiver. The terminal could operate according to any suitable scheme, including TDMA (time division multiple access) and FHSS (frequency hopped spread spectrum). The oscillator could be used in other applications such as tone generation.

Numerous changes could be made to the circuits shown in figures 3 and 4. For example, the output stage of the oscillator could be varied as required. The varicap 7 could be replaced or supplemented by one or more other forms of voltage, current or manually controlled capacitance.

The applicant draws attention to the fact that the present invention may include any feature or combination of features disclosed herein either implicitly or explicitly or any generalisation thereof, without limitation to the scope of any of the present claims. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

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CLAIMS

1. A variable frequency oscillator comprising:

an oscillatory circuit for generating a periodic output dependant on the capacitance between a first node and a second node of the circuit, and having a capacitative element connected between the first node and the second node;

the capacitative element comprising:

a variable capacitance unit, the capacitance of which is variable for varying the frequency of the output; and

a plurality of trimming capacitances each being selectively connectable between the first node and the second node to trim the frequency of the output.

2. A variable oscillator as claimed in claim 1, wherein the variable capacitance unit connected between the first node and an intermediate node, and the trimming capacitances are each selectively connectable in series with the variable capacitance unit between the intermediate node and the second node.

3. A variable oscillator as clamed in claim 2, wherein a switch is connected in series with each trimming capacitance between the intermediate node and the second node for selectively connecting the respective trimming capacitance between the intermediate node and the second node in response to a respective switching signal.

4. A variable oscillator as claimed in claim 3, wherein each switch is a switching transistor.

5. A variable oscillator as claimed in any preceding claim, comprising control apparatus for causing a set of the trimming capacitances to be connected between the first node and the second node.

6. A variable oscillator as claimed in claim 5 as dependent directly or indirectly on claim 3, wherein the control apparatus is capable of generating the said switching signals.

7. A variable oscillator as claimed in claim 5 or 6, comprising a memory coupled to the control apparatus for storing information defining one or more sets of the trimming capacitances.

8. A variable oscillator as claimed in claim 7, wherein each of the said one or more sets corresponds to a respective operating frequency of the oscillator.

9. A variable oscillator as claimed in claim 7 or 8, wherein the control apparatus is capable of retrieving from the memory information defining a set of the trimming capacitances and causing that set of the trimming capacitances to be connected between the first node and the second node.

10. A variable oscillator as clamed in any preceding claim, wherein at least one of the trimming capacitances has a different capacitance value from another of the trimming capacitances.

11. A variable oscillator as claimed in any preceding claim, wherein the capacitance of the variable capacitance unit is variable by means of the voltage applied to a variable capacitance input.

12. A variable oscillator as claimed in claim 11, comprising feedback apparatus connected between the output and the variable capacitance input for stabilising the oscillator.

13. A variable oscillator as claimed in claim 12, wherein the feedback apparatus is a phase-locked loop.

14. A variable oscillator as claimed in any preceding claim, wherein the variable capacitance unit is a variable capacitance diode.

15. A radio terminal comprising a variable oscillator as claimed in any preceding claim.

16. A method for operating a variable frequency oscillator as claimed in any of claims 11 to 13 as dependant directly or indirectly on claim 7, the method comprising:

retrieving from the memory information defining a set of the trimming capacitances;

connecting that set of the trimming capacitances between the first node and the second node;

comparing the voltage at the variable capacitance input with a first preset voltage range; and

if that voltage is outside the first preset voltage range determining, based on the voltage at the variable capacitance input, an adjusted set of the trimming capacitances and storing in the memory information defining that adjusted set of the trimming capacitances.

17. A method as claimed in claim 16, wherein the said step of determining is performed only if the voltage at the variable capacitance input is inside a second preset voltage range.

18. A method as claimed in claim 16 or 17, wherein, in the step of storing, the information defining the adjusted set of the trimming capacitances is stored so as to replace in the memory the said information defining a set of the trimming capacitances.

19. A variable oscillator substantially as herein described with reference to figures 3 and 4 of the accompanying drawings.

20. A method for operating a variable oscillator substantially as herein described with reference to figures 3 and 4 of the accompanying drawings.

ABSTRACT

VARIABLE OSCILLATOR

A variable frequency oscillator comprising: an oscillatory circuit for generating a periodic output dependant on the capacitance between a first node and a second node of the circuit, and having a capacitative element connected between the first node and the second node; the capacitative element comprising: a variable capacitance unit, the capacitance of which is variable for varying the frequency of the output; and a plurality of trimming capacitances each being selectively connectable between the first node and the second node to trim the frequency of the output.

Figure 3

Fig. 1

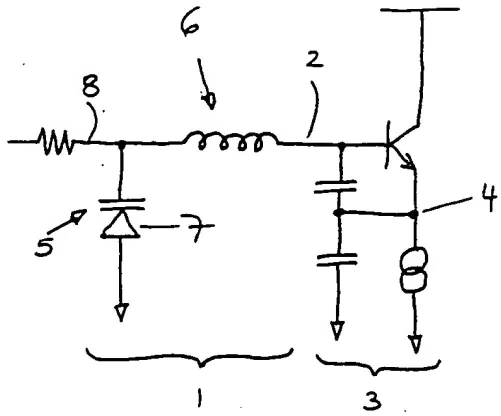


Fig. 2

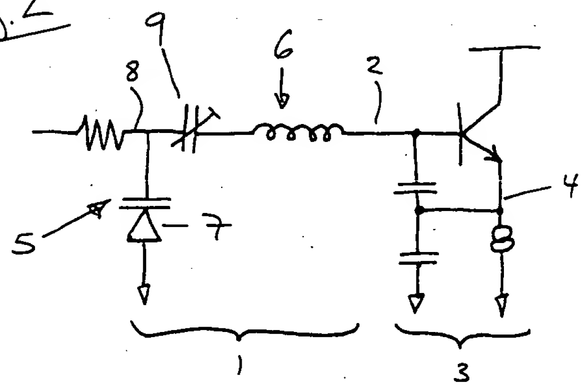


Fig. 3

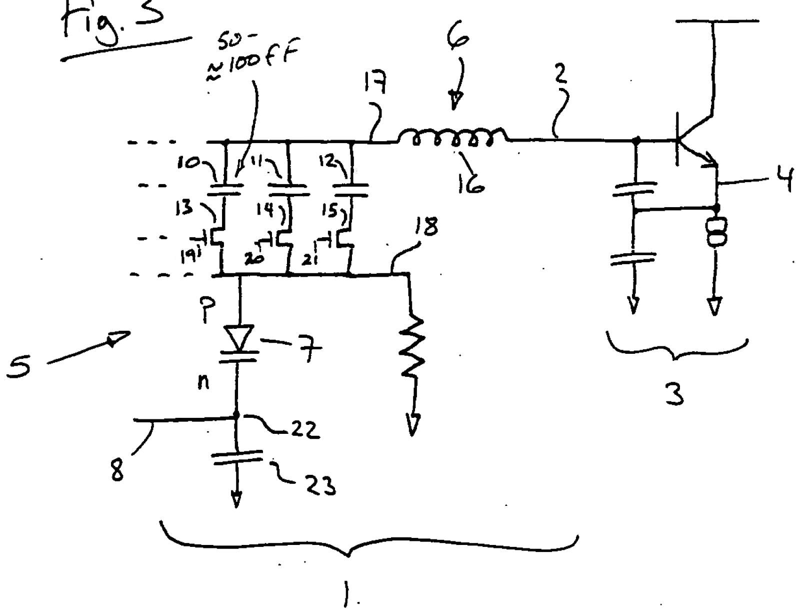
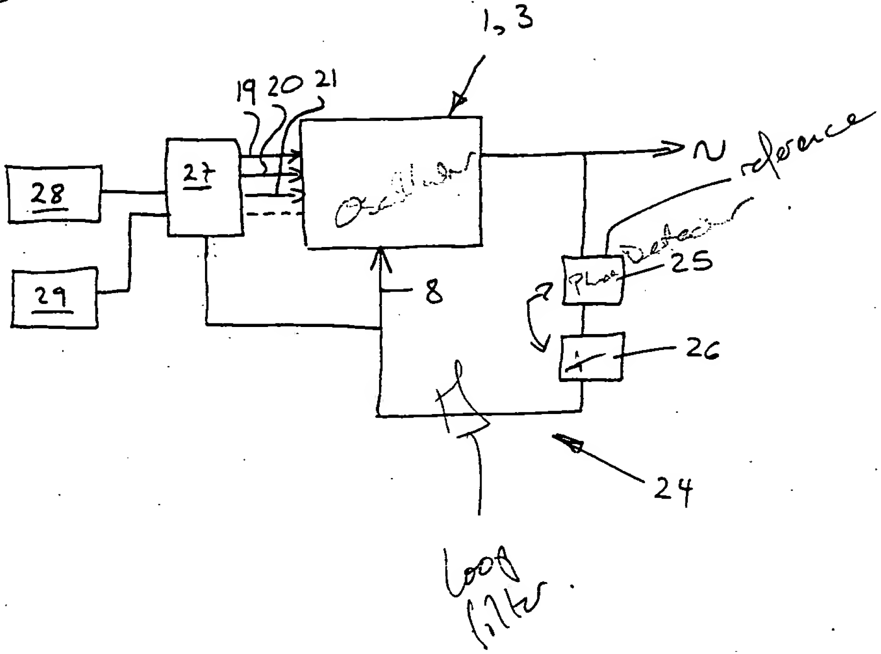


Fig. 4


1, 3
19
20
21
28
27
29
Oscillator
~ reference
Phase Detector
25
8
26
24
Loop filter